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Woods with *Quercus petraea* (Matt.) Liebl. in Tuscany (Italy): a vegetation classification approach

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Abstract. In Tuscany (Italy), oak mixed woods with high cover values of *Quercus petraea* are rather infrequent but well documented within local and national phytosociological studies, even if, in the literature, not always analyzed and well characterized from the syntaxonomic view point. We gathered 71 published and unpublished Tuscan phytosociological relevés where *Q. petraea* was dominant or with relevant cover values, that were investigated by means of multivariate analysis. The ecological requirements of the resulting groups were indirectly calculated by means of Ellenberg Indicator Values (EIV), and the fidelity coefficient (PHI) for the diagnostic species of each group was calculated. According to our analysis, five different types of *Q. petraea* woods were found to be present in Tuscany. Each group was characterized floristically and ecologically, allowing to investigate their syntaxonomic aspects. Thus we have attributed the Tuscan *Q. petraea* communities to five different associations, two of which already existing and three are here described as new associations. In the end, some conservation aspects of these woods regarding Natura 2000 habitats are discussed.
Keywords: Ecology; Distribution; Phytosociology; Sessile oak; Syntaxonomy; Vegetation

Bosques de *Quercus petraea* (Mastt.) Liebl. de la Toscana (Italia): clasificación de la vegetación

Resumen. En la región de la Toscana (Italia), los robledales con altos valores de cobertura de *Quercus petraea* son bastante infrecuentes pero están bien documentadas en los estudios fitosociológicos locales y nacionales, incluso si en la literatura no siempre se analizan y caracterizan bien desde el punto de vista sintaxonómico. Recopilamos 71 datos fitosociológicos de esta región publicados y no publicados en los que *Q. petraea* aparece como dominante o con valores de cobertura relevantes y que se han analizado mediante análisis multivariante. Los requisitos ecológicos de los grupos resultantes se calcularon indirectamente mediante los valores del indicador de Ellenberg (EIV), y se calculó el coeficiente de fidelidad (PHI) para las especies de diagnóstico de cada grupo. Los resultados del análisis mostraron cinco tipos diferentes de bosques de *Q. petraea* en la Toscana. Cada grupo está caracterizado por un elenco florístico concreto y unos requisitos ecológicos diferenciados que nos ha permitido investigar sus aspectos sintaxonómicos. Así podemos atribuir las comunidades toscanas de *Q. petraea* a cinco asociaciones diferentes, dos de las cuales ya existen y tres son descritas en este trabajo como nuevas asociaciones. También se discuten algunos aspectos de conservación de estos bosques con respecto a los hábitats Natura 2000.
Keywords: Ecology; Distribution; Phytosociology; Sessile oak; Syntaxonomy; Vegetation.

Introduction

Quercus petraea (Matt.) Liebl., which encompasses a group of several infraspecific taxa, has a fundamentally European distribution, with some ramifications towards southern Europe and the Mediterranean basin (www.emplantbase.org). In Italy, it can be considered as a rather common species in the Alps and pre-Alps but it becomes more and more sporadic proceeding southwards (Andreis & Cerabolini, 1993; Viciani & Moggi, 1997; Andreis & Sartori, 2011; Viciani & *al*., 2016a). In Italy *Q. petraea* generally lives in forests dominated by other tree species, and the woods where it can be found to have a relevant cover value or to be the dominant tree are very rare, especially in central and southern part of the country. The sociological aspects of Italian forests in which this oak plays an important role have been subjected to several past studies, but mainly based on local approaches that have led to an extremely differentiated and fragmented syntaxonomical framework (e.g. Oberdorfer & Hofmann, 1967; Pedrotti & *al*., 1982; Brullo, 1984; Scoppola & *al*., 1990; Blasi & *al*., 1990; Arrigoni, 1997; Viciani & Moggi, 1997; Foggi & *al*., 2000; Biondi & *al*., 2002; Di Pietro & *al*., 2010; Andreis & Sartori, 2011). In a recent study, Viciani & *al*. (2016a) analyzed the coenological and chorological features of the Italian communities dominated by *Q. petraea* with respect to the European context, and highlighted the presence of homogeneous floristic, chorological and ecological groups that, from the syntaxonomical point of view, allowed to attribute the Italian *Q. petraea* woods to seven alliances of three different orders. From this starting point, we focused on

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Tuscan relevés and investigated the floristic-ecological traits of *Q. petraea* woods, with the aim to search for the presence of floristic-sociological different groups, identify the diagnostic species of these groups and propose a classification at the association level for the communities of this territory.

Methods

Data collection and analyses

The study followed the standard approach of the Zürich-Montpellier School (Braun-Blanquet, 1964; Westhoff & van der Maarel, 1978) according to fundamental and updated concepts recommended by Dengler & *al.* (2005), Dengler & *al.* (2008), Biondi (2011), Pott (2011). We searched in all the Tuscan vegetation literature for phytosociological relevés in which *Q. petraea* was present and we added unpublished relevés owned by us. The first dataset consisted of more than 100 relevés. Among all these relevés we then selected only those in which *Q. petraea* played an important role in the canopy, i.e. where *Q. petraea* had cover values 3, 4 and 5 of Braun-Blanquet scale, in order to avoid doubtful environmental correlations with low cover of this oak. After this procedure, the resulting subset was composed by 71 relevés (of which, 19 were unpublished), which constituted the dataset for the analyses. The distribution of the sampled sites is graphically shown in Figure 1, while more precise locations and data of the relevés, together with bibliographical references, are reported in Supplement 1. The sporadic species, i.e. species present in less than four relevés (< 5%) and with cover-abundance values ≤ 2 were disregarded in the numerical analyses. The Braun-Blanquet cover-abundance scale were transformed according to the ordinal scale proposed by Van der Maarel (1979) and Noest & *al.* (1989); the resulting matrix (71 relevés × 101 species) was numerically classified by cluster analysis using standard statistical software as SYN-TAX 2000 (Podani, 2001) and PAST (Hammer & *al.*, 2001). We performed several algorithms and similarity measures, which gave very similar results. The dendrogram showed was performed with “paired group” as algorithm and Bray-Curtis index as similarity measure.

The diagnostic species among the groups resulting from cluster analysis were statistically defined by the PHI coefficient of association (Chytrý & *al.*, 2002), and performed using the *indicspecies* package (De Caceres & Legendre, 2009) in the R environment (R Core Team, 2015). The significance of the fidelity coefficient was verified according to a Fisher’s exact test. We considered a species as diagnostic of each group if phi ≥ 0.40 and $p < 0.05$; the threshold values (phi = 0.40) is chosen because it produces neither too long nor too short lists of diagnostic species for each vegetation unit (Illyés & *al.*, 2007). The number of relevés of each cluster was virtually standardized to an equal size (Tichý & Chytrý, 2006) in order to eliminate dependency of the PHI coefficient for presence/absence data on the relative size of groups within data set.

Exploratory analysis of floristic variations within Tuscan *Q. petraea* woods as function of environmental variables was performed through Ellenberg Indicators Values (EIV, see Ellenberg & *al.*, 2001; Pignatti, 2005). In particular, we considered the following factors: Light (L), Temperature (T), Moisture (U), Nitrogen (N), Continentality (C) and Soil pH (R). For each relevé, each total indicator value was calculated using the weighted averages of the presence/absence data of the species recorded in the plot (except for sporadic species). Differences in mean EIVs among relevés and groups were displayed by NMDS analysis, with Simpson index as similarity measure, performed using PAST statistical software (Hammer & *al.*, 2001).

Vascular plant species names follow mainly Conti & *al.* (2005, 2007) and Pignatti (1982). The relevés were stored in the vegetation data archiving project “VegItaly” (Landucci & *al.*, 2012; Gigante & *al.*, 2012; Venanzoni & *al.*, 2012).

Results and Discussion

The Tuscan *Q. petraea* wood relevés are reported in Supplement 2, grouped according to the results of cluster analysis (dendrogram of Supplement 3). We can distinguish five principal groups within the data set. The groups are well separated on a floristic basis, as showed by the results of PHI analysis (Table 1), and also distinguished on ecological bases, as highlighted by the NMDS analysis (Figure 2). The length and the orientation of the vectors associated with environmental variables depicted their importance in structuring *Q. petraea* vegetation types in Tuscany (Figure 2). The vector associated with continentality (C) resulted to be very short, thus suggesting that this variable had overall low importance in structuring woodland vegetation, while the most important ecological factors appeared to be light (L), soil pH (R) and nitrogen availability (N) (Figure 2).

The first main division of the dendrogram (Supplement 3) separates the relevés in which presence and cover values of the Mediterranean species (*Quercetea ilicis*) are less relevant from the relevés in which these components are better represented (Supplement 2). In the first subcluster, two main groups can be separated. The first one (Group 1) encompasses rather mesophilous woods, while the second one (Group 2) comprises relatively open woods on very acidic and nutrient-poor substrates (Figure 2). The second main division of the dendrogram encompasses relatively more thermophilous and less acidic woods that can be separated in three subclusters (Groups 3, 4 and 5), always on floristic and ecological bases (Table 1, Figure 2).

We prepared two synoptic tables, one to compare the Tuscan groups of relevés each other (Supplement 4), and another comparing the detected Tuscan groups with the most similar associations from literature (Supplement 5).

Table 1. Diagnostic species according to Φ values of the 5 different groups resulting from cluster analysis of Tuscan woods with relevant cover of *Quercus petraea*. In bold the frequency (%) of species in each group; only the species with a Φ value >0.4 are indicated.

N. relevés				10	32	15	7	7
Cluster Group				1	2	3	4	5
Fidelity coefficient	Φ	*p-value*						
Lonicera caprifolium	0.807	0.001	***	**70**	0	0	0	0
Clinopodium vulgare	0.667	0.002	**	**50**	0	0	0	0
Rosa arvensis	0.667	0.002	**	**50**	0	0	0	0
Serratula tinctoria	0.638	0.001	***	**80**	16	0	14	14
Ajuga reptans	0.590	0.002	**	**40**	0	0	0	0
Malus florentina	0.590	0.002	**	**40**	0	0	0	0
Calluna vulgaris	0.559	0.001	***	**40**	3	0	0	0
Juniperus communis	0.544	0.003	**	**90**	28	40	29	0
Crataegus laevigata	0.454	0.019	*	**40**	3	13	0	0
Genista germanica	0.447	0.022	*	**40**	3	0	0	14
Pteridium aquilinum	0.779	0.001	***	40	**97**	0	0	0
Molinia arundinacea	0.682	0.001	***	10	**63**	0	0	0
Pinus pinaster	0.682	0.001	***	10	**63**	0	0	0
Frangula alnus	0.667	0.001	***	0	**50**	0	0	0
Rubus hirtus	0.448	0.015	*	10	**34**	0	0	0
Brachypodium rupestre	0.418	0.032	*	10	**31**	0	0	0
Daphne laureola	0.829	0.001	***	0	0	**73**	0	0
Ostrya carpinifolia	0.829	0.001	***	0	0	**73**	0	0
Cornus mas	0.719	0.001	***	20	0	**100**	43	0
Acer monspessulanum	0.691	0.001	***	0	0	**53**	0	0
Pyracantha coccinea	0.691	0.001	***	0	0	**53**	0	0
Pyrus pyraster	0.586	0.003	**	0	6	**47**	0	0
Luzula forsteri	0.551	0.005	**	30	9	**73**	14	0
Carex sylvatica	0.535	0.009	**	0	**0**	**33**	0	0
Sanicula europea	0.535	0.010	**	0	**0**	**33**	0	0
Melampyrum italicum	0.475	0.013	*	0	**0**	**27**	0	0
Vinca minor	1.000	0.001	***	0	0	0	**100**	0
Laurus nobilis	0.779	0.001	***	0	3	0	**100**	43
Allium pendulinum	0.718	0.001	***	0	0	0	**57**	0
Neottia nidus-avis	0.718	0.001	***	0	0	0	**57**	0
Pulmonaria hirta	0.718	0.001	***	0	0	0	**57**	0
Acer campestre	0.674	0.001	***	10	9	27	**86**	0
Melica uniflora	0.601	0.002	**	40	6	20	**86**	0
Asplenium onopteris	0.494	0.005	**	0	0	0	**43**	14
Mespilus germanica	0.485	0.010	**	0	16	0	**43**	0
Smilax aspera	0.924	0.001	***	0	0	13	0	**100**
Juniperus oxycedrus	0.816	0.001	***	0	0	0	0	**71**
Sorbus aria	0.793	0.001	***	0	3	0	0	**71**
Phillyrea latifolia	0.791	0.001	***	0	0	20	0	**86**
Cyclamen repandum	0.766	0.001	***	0	9	40	0	**100**
Carex humilis	0.492	0.020	*	0	0	0	0	**29**

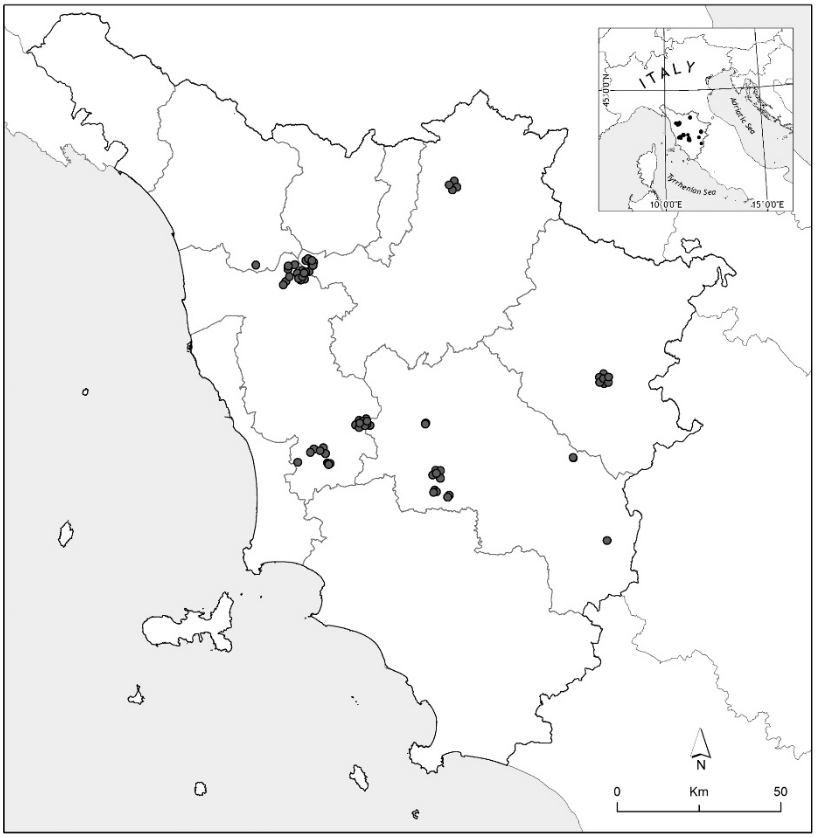

Figure 1. Location of the study area and distribution map of the Tuscan *Quercus petraea* wood relevés.

The sociological groups

Group 1. Mixed woods of *Q. petraea* and *Q. cerris* occasionally present at hilly and submontane altitudes on alluvial deposits and marly-arenaceous substrata in northern, central and eastern Tuscany (Figure 3). It is the relatively most meso-hygrophilous group (Figure 2). The herb layer is composed of mesophilous and averagely to highly acidophilous species, while termophilous species are sporadic or lacking. *Ilex aquifolium*, which occurs in the majority of the other groups, is here lacking (Supplement 2).

Differential species: *Serratula tinctoria*, *Crataegus laevigata*, *Clinopodium vulgare*, *Rosa arvensis*, *Lonicera caprifolium*, *Ajuga reptans*, *Calluna vulgaris*, *Juniperus communis*, *Genista germanica*, *Malus florentina* (Table 1). Other coenological important species (though not significant as to PHI analysis): *Genista pilosa*, *Poa nemoralis* (Supplement 2).

Syntaxonomy: relevés very similar to those of Group 1, located in a sub-Mediterranean hilly environment in Emilia Romagna, were described by Ubaldi & *al*. (1995) as a new association named *Serratulo tinctoriae-Quercetum petraeae*. We can note some floristic minor differences (i.e. a greater cover of *Quercus pubescens* and the presence of *Iris graminea, Symphytum tuberosum, Viburnum lantana,* and others in Emilia conenoses, see Supplement 5), but the specific-characteristic composition is very close to that one of Group 1, so we can use this syntaxon. A nomenclatural issue must be solved, because in a later work, Ubaldi (2003) considered *Serratulo-Quercetum* a new association, based on the same table of Ubaldi & *al*. (1995) and separated the original table in two subassociations, *typicum* and *paeoniaetosum*, providing a new type relevé also for the subassociation *typicum*. This is in contrast with the International Code of Phytosociological Nomenclature (Weber & *al*., 2000), because the *Serratulo-Quercetum typicum* resulted to be correctly described and typified in Ubaldi & *al*. (1995).

Group 2. Mixed and relatively open woods of *Q. petraea*, *Q. cerris* and *Pinus pinaster*, occurring in central and central-southern Tuscany (Figure 3), on acid and poor-nutrient soils (Figure 2), mainly coming from "Verrucano" geological unit (metaconglomerates, metasandstones, quartzites, metavolcanic rocks, etc.). Many acidophilous shrubs and herbs occur in the dominated layers, together with some meso-hygrophilous species (Supplement 2). Two different aspects, influenced by human management, can be identified: a first one, with *P. pinaster* absent or sporadic (subgroup 2a, mainly located in Merse and Farma valleys, central-southern Tuscany); a second one, having a more open canopy, characterised by a stronger presence of *P. pinaster* in the dominant layer and various shrubs (especially *Rubus* sp.) in the undergrowth, due to frequent coppicing and conifer plantations (subgroup **2b**, mainly located in Cerbaie site, central Tuscany). The last four relevés on the right of subgroup 2b are somehow differentiated, as results from the dendrogram, probably due to the presence of *Quercus robur* and other mesohygrophilous species.

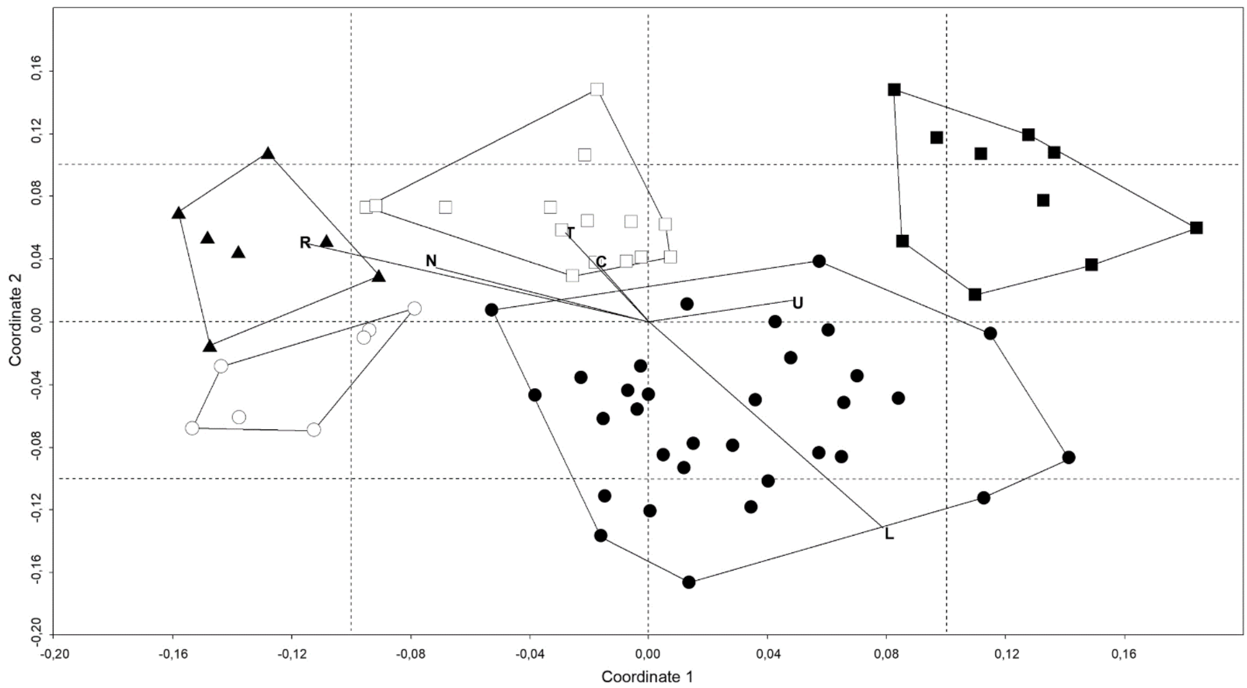

Figure 2. NMDS ordination diagram for the 71 relevés of the Tuscan *Quercus petraea* woods. ■ = Group 1; ● = Group 2; □ = Group 3; ○ = Group 4; ▲ = Group 5. Vectors: Light (L), Temperature (T), Moisture (U), Nitrogen (N), Continentality (C), Soil pH (R).

Differential species: *Pteridium aquilinum*, *Molinia arundinacea*, *Frangula alnus*, *Pinus pinaster*, *Rubus hirtus* and *Brachypodium rupestre* (Table 1). Other coenological important species (though not significant as to PHI analysis): *Anemone nemorosa*, *Cytisus scoparius*, *Castanea sativa* and *Erica scoparia* (Supplement 2).

Syntaxonomy: these communities can be attributed to the association *Frangulo alni-Quercetum petraeae* Arrigoni in Foggi & *al*. 2000 described by Arrigoni (1997) for Cerbaie, Tuscany (with the name *Ilici aquifolii-Quercetum petraeae* Arrigoni 1997 nom. illeg.). In our analysis this vegetation type completely overlaps with *Hieracio racemosi-Quercetum petraeae fraxinetosum orni* Arrigoni 1997, described for the same area by the same author: the type relevés of *Frangulo alni-Quercetum* and *Hieracio racemosi- Quercetum fraxinetosum* fall within the subgroup 2b (rel. n. 59 and 67 in Supplement 2). *Frangulo-Quercetum* is rather similar to *Hieracio racemosi-Quercetum petraeae* Pedrotti, Ballelli & Biondi 1982 (described for Gubbio basin, Umbria) from which it differs for the presence of several thermophilous species lacking in Gubbio relevés (see Supplement 5). Ubaldi (2003) noted this difference and using Arrigoni's relevés of *Hieracio racemosi-Quercetum* described a new association named *Lonicero etruscae-Quercetum petraeae* Ubaldi 2003, which in our opinion must be considered a synonym of *Frangulo alni-Quercetum petraeae*.

Group 3. Mixed woods of *Q. petraea*, *Q. cerris* and *Ostrya carpinifolia* which can be found in central Tuscany (Val di Cecina, Berignone-Tatti) (Figure 3), on relatively nutrient-rich (Figure 2) disrupted rocks substrata (sandstones of Ponsano and clays, shales, limestones, siltstones, marls of "argille scagliose" geological unit). Many nemoral species both mesophilous (*Carpinus betulus*, *Cornus mas*), and termophilous (*Quercus ilex*, *Arbutus unedo*, *Viburnum tinus*) occur in the dominated wood layer, together with several trees and shrubs typical of the previous dynamical stages (*Sorbus domestica*, *Acer monspessulanum*, *Pyracantha coccinea*, *Pyrus pyraster*, *Emerus major*). In the herb layer there is a balanced presence of mesophilous and termophilous species while only some acidophilous species are frequently occurring (e.g. *Luzula forsteri*, *Festuca heterophylla*, *Solidago virgaurea*) (Supplement 2, Table 2).

Differential species: *Cornus mas*, *Daphne laureola*, *Ostrya carpinifolia*, *Luzula forsteri*, *Pyrus pyraster*, *Acer monspessulanum*, *Pyracantha coccinea*, *Carex sylvatica*, *Primula vulgaris*, *Sanicula europaea* and *Melampyrum italicum* (Table 1, Table 2). Other coenological important species (though not significant as to PHI analysis): *Emerus major*, *Ilex aquifolium*, *Primula vulgaris* and *Anemone nemorosa.*

Syntaxonomy: These peculiar oak communities were well known and described from the forestry view point (Barsacchi & *al*., 1997), but to our knowledge no existing syntaxon can be used to encompass them. Some rather similar associations, dominated by Turkey oak or sessile oak, have been established, but some important coenological and nomenclatural differences prevent their use; the closer ones are (see Supplement 5): i) *Melico uniflorae-Quercetum cerridis* Arrigoni, Mazzanti & Ricceri 1990, described for Tuscan Maremma but also reported for other Thyrrenian areas (e.g. northern Latium, see Di Pietro & *al*., 2010), which is more mesophilous, since in Group 3 relevés species as *Melica uniflora*, *Euphorbia amygdaloides*, *Oenanthe pimpinelloides* or *Lathyrus venetus* are sporadic or lacking and, on the contrary, thermophilous plants are numerous and have high cover values; ii) *Allio pendulini-Quercetum cerris* (De Domincis & Casini 1979) Ubaldi & *al*. 1990 ex Ubaldi 1995, based on relevés by De Domincis & Casini (1979) and described for Tuscan Colline Metallifere area, but with some floristic differences and with a type relevé lacking of *Q. petraea* (Ubaldi, 1995); iii) *Asplenio adianti-nigri-Quercetum cerris* (Pedrotti & *al*., 1979) Ubaldi & *al*., 1990 ex Ubaldi 1995, described for Umbria, with a more open canopy and several important floristic and phytogeographic differences (e.g. *Teucrium siculum* instead of *T. scorodonia*); iv) *Rubio peregrinae-Quercetum cerridis*, described for northern Latium by Di Pietro & *al*. (2010) but also reported for southern Tuscany (Viciani & Gabellini, 2013), more thermophilous and with significant floristic differences (e.g. *Anemone apennina* vs. *A. nemorosa*, presence of *Carpinus orientalis*); v) *Carici olbiensis-Quercetum petraeae*, described for northern Latium by Di Pietro & *al*. (2010) and very similar as habitat type, but with crucial floristic and phytogeographic differences (e.g. constant presence of *Carex olbiensis, Teucrium siculum, Fagus sylvatica, Mespilus germanica*, lacking of *Physospermum cornubiense*). For these reasons, we therefore propose to establish a new association for Group 3 communities, named *Corno maris-Quercetum petraeae ass. nova hoc loco, holotypus* rel. 5 in Supplement 2, Table 2.

Table 2. *Corno maris-Quercetum petraeae ass. nova.* (cluster group 3)
(*Crataego-Quercion cerridis*, *Quercetalia pubescenti-petraeae*, *Quercetea pubescentis*)

Reference n.	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Relevé N.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Differentials of ass.															
**Cornus mas*	+	+	2	2	1	r	1	+	+	1	1	1	+	+	+
**Daphne laureola*	r	+	r	r	+	+	.	+	+	+	+	+	.	.	.
**Ostrya carpinifolia*	1	4	.	.	2	.	3	2	3	1	2	2	.	2	2
**Luzula forsteri*	.	+	+	+	r	+	r	+	+	+	+	+	.	.	.
**Pyrus pyraster*	.	.	.	.	2	1	r	.	r	r	+	+	.	.	.
**Acer monspessulanum*	.	.	.	.	2	1	.	+	+	.	1	1	.	1	1
**Pyracantha coccinea*	+	+	.	.	+	.	.	r	r	+	+	+	.	.	.
**Carex sylvatica*	.	r	.	.	.	.	.	+	+	+	.	.	+	.	.
**Sanicula europea*	.	.	.	.	.	.	.	+	+	r	+	+	.	.	.
**Melampyrum italicum*	.	.	1	1	+	+	.	.	.	.	.	.	.	.	.
Other acidophilous species															
Quercus petraea	4	5	4	5	3	5	3	4	4	3	5	5	4	4	4
Festuca heterophylla	1	+	1	1	1	+	+	1	1	1	1	1	+	+	+
Ilex aquifolium	2	.	2	2	+	2	.	1	1	.	1	1	1	1	1
Solidago virgaurea	.	.	1	1	+	1	+	+	+	+	+	+	+	.	.
Physospermum cornubiense	r	.	+	+	1	.	.	r	r	.	.	.	+	r	r
Teucrium scorodonia	.	.	.	.	.	.	.	+	+	.	r	r	.	+	+
Poa nemoralis	.	.	r	r	+	.	.	.	.	.	r	r	.	.	.
Stachys officinalis	.	.	.	.	+	+	.	.	.	.	.	.	.	r	r
Genista pilosa	r	r	.	.	.	.	.	.	.	.	.	.	.	.	.
Veronica officinalis	.	+	.	.	.	r	.	.	.	.	.	.	.	.	.
Characteristics of *Crataego-Quercion* and higher															
Fraxinus ornus	3	1	3	3	2	4	1	1	1	2	1	1	1	2	3
Sorbus torminalis	+	.	1	1	+	2	+	+	+	+	+	+	1	.	.
Brachypodium sylvaticum	+	r	+	+	+	+	r	.	.	+	r	r	+	.	.
Carpinus betulus	1	.	1	1	.	.	.	1	1	3	4	4	1	1	1
Quercus cerris	2	2	3	3	3	2	5	3	3	3	.	.	.	.	.
Cyclamen hederifolium	+	.	1	1	1	1	+	1	1	.	1	1	.	.	.
Emerus major subsp. *major*	.	.	+	+	+	.	.	+	+	r	+	+	.	r	r
Anemone nemorosa	.	+	+	+	+	+	.	1	1	.	+	+	.	.	.
Crataegus monogyna	+	+	+	+	2	.	+	.	.	+	+	+	.	.	.
Sorbus domestica	1	.	1	1	1	1	+	.	.	.	1	1	.	.	.
Viola alba subsp. *dehnhardtii*	.	.	.	.	.	.	r	+	+	r	r	r	.	r	r
Lonicera etrusca	.	.	+	+	+	+	.	.	.	+	+	+	.	.	.
Malus sylvestris	+	r	.	.	.	.	.	+	+	.	+	+	.	.	.

Juniperus communis	.	.	r	r	.	+	.	.	.	.	.	.	+	+	+
Ruscus aculeatus	.	.	.	.	.	+	.	.	.	.	r	r	.	+	+
Viola reichenbachiana	.	.	.	.	+	.	.	+	+	.	+	+	.	.	.
Acer campestre	+	.	.	.	.	.	.	.	.	2	1	1	.	.	.
Digitalis micrantha	r	r	.	.	.	.	.	.	.	.	r	r	.	.	.
Primula vulgaris	.	.	.	.	r	.	.	.	.	+	r	r	.	.	.
Symphytum tuberosum	.	.	.	.	r	.	.	.	.	.	r	r	+	.	.
Melica uniflora	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.
Tamus communis	.	.	.	.	.	.	.	.	.	.	.	.	+	r	r
Lilium bulbiferum subsp. *croceum*	.	.	.	.	.	r	.	.	.	.	.	.	.	r	r
Clematis vitalba	.	.	.	.	.	.	.	.	.	+	r	r	.	.	.
Melittis melissophyllum	.	.	.	.	+	.	.	.	.	r	.	.	.	.	.
Crataegus laevigata	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.
Ligustrum vulgare	.	+	.	.	.	.	.	.	.	.	.	.	+	.	.
Euonymus europaeus	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.
Carex digitata	.	.	r	.	+	.	.	.	.	.	.	.	.	.	.
Transgressives from *Quecetea ilicis* and thermophilous species															
Quercus ilex	1	.	2	2	1	1	+	1	1	1	+	+	1	2	2
Rubia peregrina	+	+	+	+	+	+	+	1	1	.	+	+	+	1	1
Arbutus unedo	2	3	1	1	.	r	+	+	+	r	.	.	+	1	1
Cyclamen repandum	r	r	.	.	.	+	.	.	r	.	.	+	.	.	1
Viburnum tinus	.	+	.	.	.	.	.	.	.	.	r	r	1	+	+
Erica arborea	+	+	r	r	.	.	.	.	.	.	.	.	.	.	.
Phillyrea latifolia	.	.	.	.	.	+	.	.	+	.	.	.	+	.	.
Smilax aspera	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Rosa sempervirens	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.
Other species															
Hedera helix	1	2	2	2	2	2	2	3	3	2	2	2	1	1	1
Rubus ulmifolius	+	1	.	.	.	+	1	+	+	+	+	+	r	r	r
Cruciata glabra	.	r	+	.	+	.	.	+	.	+	1	.	.	.	.
Dactylis glomerata	.	.	.	.	.	+	.	.	.	.	r	r	.	.	.
Lathyrus linifolius	.	.	r	r	+	.	.	.	.	.	.	.	.	.	.
Moheringia trinervia	.	.	.	.	.	.	+	.	.	.	+	+	.	.	.
Cephalanthera longifolia	.	.	.	.	.	.	.	.	.	.	r	r	.	.	.

Relevé source: 1,4,6,12,13,15: Foggi, B. & al. 2000, Table 14: 1,2,5-8; 2: Foggi, B. & al. 2000, Table 11: 1; 3,5,7,8,10: Pisa, Berignone, UTM 32T 656687 / 4799343, *holotypus* ass. rel. 5.; 9: Pisa, Serrazano, UTM 32T 647157 / 4786731; 11,14: Viciani et al. 2017, Suppl. 1: 89, 93. (For more species see Supplement 2).

Group 4. *Q. petraea*-dominated woods located in central-eastern Tuscany (Figure 3) on sandstone substrates, rich in relatively thermophilous and also mesophilous species (Supplement 2, Table 3). Soils seem to be not so acidic and nutrient-poor (Figure 2). In the tree layer, *Quercus cerris* and *Carpinus betulus* are sporadic, while *Castanea sativa* is rather frequent. These woods must probably be interpreted as a relict of hilly forests located in favorable geomorphological and pedological sites, more widespread in the past but at present almost completely replaced by different and mainly agricultural land uses (Viciani & Moggi, 1993).

Differential species: *Vinca minor*, *Allium pendulinum*, *Pulmonaria hirta*, *Neottia nidus-avis*, *Laurus nobilis*, *Melica uniflora*, *Acer campestre*, *Asplenium onopteris* and *Mespilus germanica* (Table 1, Table 3). Other coenological important species (though not significant as to PHI analysis): *Anemone apennina*, *Prunus avium* and *Lonicera etrusca* (Supplement 2, Table 3).

Syntaxonomy: to our knowledge, no existing association can encompass these relevés. The more similar syntaxon is probably *Vinco-Quercetum cerris* (see Supplement 5), described for hilly Emilia woods (Alessandrini & *al*., 1979; Ubaldi & *al*.,1990), which shares some of the differential species, but has no thermophilous entities of *Quercetea ilicis* and shows relevant vicariances (e.g. *Anemone nemorosa* vs. *A. apennina*); moreover, the type relevé of *Vinco-Quercetum cerris* indicated by Ubaldi (1995) is a *Carpinus betulus* dominated wood without *Q. petraea*. We therefore propose to attribute Group 4 communities to a new association named *Allio pendulini-Quercetum petraeae ass. nova hoc loco, holotypus* rel. 2 in Supplement 2, Table 3.

Table 3. *Allio pendulini-Quercetum petraeae ass. nova* (cluster group 4)
(*Crataego-Quercion cerridis*, *Quercetalia pubescenti-petraeae*, *Quercetea pubescentis*)

Reference N.	58	59	60	61	62	63	64
Relevé N.	1	2	3	4	5	6	7
Differentials of ass.							
Vinca minor	1	3	3	3	+	3	2
Acer campestre	+	1	.	3	1	1	1
Laurus nobilis	+	+	+	+	1	+	1
Allium pendulinum	.	1	+	.	2	.	2
Pulmonaria hirta	.	+	.	1	1	+	.
Neottia nidus-avis	.	.	+	+	+	+	.
Melica uniflora	+	+	+	.	+	+	+
Asplenium onopteris	+	1	.	.	.	.	+
Mespilus germanica	.	.	.	+	.	+	+
Other acidophilous species							
Quercus petraea	5	4	5	4	5	5	5
Physospermum cornubiense	1	2	1	1	1	1	+
Festuca heterophylla	1	+	1	.	.	+	+
Hieracium sylvaticum/H. murorum	1	+	+	.	.	.	+
Castanea sativa	.	1	.	2	3	1	.
Solidago virgaurea	+	+	+	.	.	.	.
Cytisus scoparius	.	+	+	.	.	.	.
Characteristics of *Crataego-Quercion* and higher							
Sorbus torminalis	1	+	+	1	+	+	2
Fraxinus ornus	2	3	2	2	2	2	3
Ruscus aculeatus	+	1	+	2	3	2	3
Anemone apennina	+	3	+	.	2	1	2
Lonicera etrusca	.	1	1	2	1	+	2
Tamus communis	+	+	.	.	+	+	+
Cyclamen hederifolium	.	+	.	+	+	.	+
Prunus avium	.	+	.	+	+	.	.
Cornus mas	.	+	.	1	1	.	.
Emerus major subsp. *major*	+	+	+	.	.	.	.
Sorbus domestica	.	.	+	+	.	.	.
Crataegus monogyna	.	.	.	+	+	.	.
Juniperus communis	+	.	+	.	.	.	.
Melittis melissophyllum	+	+	.	.	.	.	.
Lilium bulbiferum subsp. *croceum*	.	.	.	.	.	+	+
Lathyrus niger	+	+	.	.	.	.	.
Laburnum anagyroides	.	2	.	.	.	.	.
Lathyrus venetus	.	1	.	.	.	.	.
Quercus cerris	1	.	.	.	.	.	.
Transgressives from *Quecetea ilicis* and thermophilous species							
Quercus ilex	.	+	1	1	+	+	1
Rubia peregrina	+	1	1	+	+	.	1
Arbutus unedo	+	+	2	+	.	.	+
Viburnum tinus	+	+	.	.	+	+	1
Erica arborea	+	+	+	.	.	+	.
Asparagus acutifolius	.	+	+	.	.	.	.
Other species							
Hedera helix	1	1	+	+	2	2	2
Dactylorhiza maculata subsp. *fuchsii*	+	+	+	.	.	.	.
Rubus ulmifolius	.	+	.	.	+	.	.

Relevé source: Viciani, D. & Moggi, G. 1997. Table 1 (rels. 1-9); *holotypus* ass rel. 2. (For more species see Supplement 2).

Group 5. Relatively open *Q. petraea*-dominated woods with abundant *Q. ilex*, located in central Tuscany (Figure 3) on soils derived by ultramafic substrates, therefore not so acidic (but with Mg instead of Ca) and nutrient-poor (Figure 2). The dominated wood layer is rich in sclerophyllous dry-tolerant species and scarce in *Q. cerris*, which on ophiolite rocks seems to be less competitive than *Q. petraea* (Supplement 2).

Differential species: *Phillyrea latifolia*, *Smilax aspera*, *Sorbus aria*, *Juniperus oxycedrus* ssp. *oxycedrus*, *Cyclamen repandum* and *Carex humilis* (Table 1, Table 4). Other coenological important species (though not significant as to PHI analysis): *Anemone apennina*, *Laurus nobilis*, *Stachys officinalis* and *Hieracium racemosum* (Supplement 2, Table 4).

Syntaxonomy: these peculiar communities were not described before and syntaxa with similar characteristics are not present in literature, so we propose to attribute them to a new association named *Junipero oxycedri-Quercetum petraeae ass. nova hoc loco, holotypus* rel. 3 in Supplement 2, Table 4.

Table 4. *Junipero oxycedri-Quercetum petraeae ass. nova* (cluster group 5)
(*Crataego-Quercion cerridis*, *Quercetalia pubescenti-petraeae*, *Quercetea pubescentis*)

Reference. N.	65	66	67	68	69	70	71
Relevé N.	1	2	3	4	5	6	7
Differentials of ass.							
Smilax aspera	+	+	+	1	+	+	+
Cyclamen repandum	+	2	+	+	+	+	+
Phillyrea latifolia	1	1	2	1	1	1	.
Sorbus aria	2	1	.	+	1	1	.
Juniperus oxycedrus subsp. *oxycedrus*	+	2	1	.	1	r	.
Carex humilis	2	1	.	.	.	.	.
Other acidophilous species							
Quercus petraea	3	3	5	5	4	4	5
Stachys officinalis	1	+	.	+	1	+	.
Physospermum cornubiense	.	.	+	+	.	+	+
Solidago virgaurea	1	.	.	r	+	.	.
Hieracium racemosum	.	.	.	.	+	r	+
Erica scoparia	.	+	.	.	.	+	1
Festuca heterophylla	.	.	.	1	.	1	.
Hieracium sylvaticum/H. murorum	.	.	r	.	.	.	+
Ilex aquifolium	.	.	.	.	.	.	1
Castanea sativa	.	.	.	.	.	.	1
Characteristics of *Crataego-Quercion* and higher							
Sorbus torminalis	+	1	1	1	2	+	+
Fraxinus ornus	2	2	2	3	3	3	1
Ruscus aculeatus	+	3	3	3	3	2	.
Brachypodium sylvaticum	+	1	+	+	+	1	.
Cyclamen hederifolium	2	+	1	2	1	1	.
Viola alba subsp. dehnhardtii	+	+	+	.	+	+	.
Tamus communis	.	+	1	+	+	+	.
Anemone apennina	.	.	.	+	1	1	r
Melittis melissophyllum	r	.	r	+	.	r	.
Laurus nobilis	.	.	2	1	1	.	.
Symphytum tuberosum	.	.	.	+	+	.	.
Quercus cerris	.	.	.	.	.	2	.
Transgressives from *Quercetea ilicis* and thermophilous species							
Quercus ilex	2	2	3	2	1	2	2
Rubia peregrina	+	+	+	+	+	+	.
Arbutus unedo	+	1	1	.	1	.	2
Erica arborea	1	+	1	.	1	.	.
Viburnum tinus	.	.	.	.	.	.	1
Other species							
Cruciata glabra	+	.	.	+	+	+	.
Rubus ulmifolius	.	.	+	r	+	.	.
Hedera helix	.	.	.	+	.	r	.
Cephalanthera rubra	.	.	.	r	r	.	.

Relevé source: Viciani et al. 2017, Suppl. 1: 105, 107-111; *holotypus ass.* rel. 3. (For more species see Supplement 2).

Considerations on other *Q. petraea* associations reported for Tuscany and attribution to higher syntaxonomic ranks

In Italian phytosociological literature, one of the most recalled associations regarding central Italy *Q. petraea* communities is *Physospermo-Quercetum petraeae*, reported by Oberdorfer & Hofmann (1967) for northern Apennines, used also for central Tuscan coenoses (e.g. by Landi & *al*., 2009) but located only on northern slopes (facing Po Valley) of Liguria and Emilia Apennines, as evidenced by Viciani & *al*. (2016a). Moreover, *Physospermo-Quercetum petraeae* is the type association of *Erythronio-Quercion petraeae* Ubaldi & *al*. 1990 (which is considered now a synonym of *Physospermo-Quercion petraeae* A.O. Horvát 1976, see Mucina & *al*., 2016), not occurring in Tuscany (Viciani & *al*., 2016a). *Physospermum cornubiense* is widely present also in our relevés but, as showed by our analysis, it is not discriminating of any *Q. petraea* vegetation type in Tuscany. Some communities similar to *Physospermo-Quercetum petraeae* could have been located in the past also in the Tuscan slopes of the Apennines, but as can be derived from the general distribution of the relevés (Figures 1, 3), at present *Q. petraea* is rather rare in the Tuscan Apennines and generally does not form woods in which it has relevant covers, because it has been extensively substituted by *Castanea sativa* plantations at higher altitudes and by agricultural land uses at lower altitudes (Bernetti, 1987; Arrigoni & Viciani, 2001; Viciani & *al*., 2016a). Due to these considerations and to the above mentioned floristic and coenological features of Tuscan *Q. petraea* coenoses, in accordance with Viciani & *al*. (2016a), we therefore propose to attribute all the Tuscan *Q. petraea* associations to *Crataego laevigati-Quercion cerridis* Arrigoni 1997 alliance. Probably, *Serratulo-Quercetum petraeae*, especially in the form of northern Tuscany (Mugello) conenoses, can be considered close to a sort of transition towards *Physospermo-Quercion petraeae* associations, while *Frangulo alni-Quercetum petraeae* is not so far from some aspects of the northern Italian *Quercion roboris* (see Andreis & Sartori, 2011). The attribution of all the Tuscan associations to *Crataego laevigati-Quercion cerridis* is reinforced also by bioclimatic and phytogeographic considerations, since relevés are all located in a generally sub-Mediterranean environmental context (see Blasi, 2010; Blasi & *al*., 2014; Pesaresi & *al*., 2014). Respect to higher syntaxonomic ranks, the syntaxonomic order generally accepted is *Quercetalia pubescenti-petraeae*, while at the class level there are some discrepancies between the Italian schemes (Biondi & *al*., 2014; Biondi & Blasi, 2015) and the European ones (Mucina & *al*., 2016) that cannot be here solved.

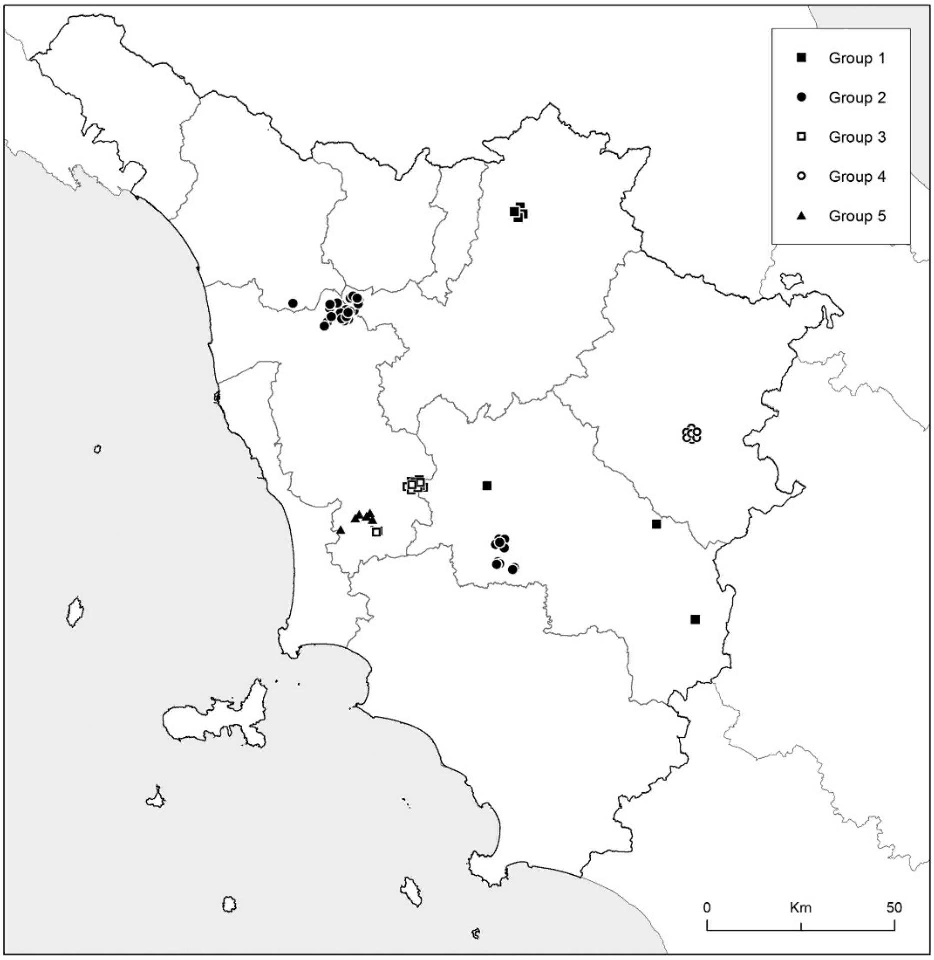

Figure 3. Distribution map of the resulting Tuscan *Quercus petraea* wood groups.

Conservation aspects

The study of vegetation with the phytosociological approach is crucial for detecting many habitats of conservation interest in accordance with the European Habitat Directive 92/43/EEC (Biondi & *al*., 2012; European Commission, 2013; Viciani & *al*., 2014, 2016b, 2017; Gigante & *al*., 2016; Angiolini & *al*., 2017). This is true also for woods, and the conservation importance of several forest types have been recognized and listed in the Habitat Directive as different types of conservation interest habitats. As to woods where *Q. petraea* has an important role, the Habitat Directive lists several habitats with different Natura 2000 codes (e.g. for Italy: 9110, 9170, 91L0, 91M0, see Biondi & Blasi, 2009; European Commission, 2013; Janssen & *al*., 2016). EU habitat types are mostly described at the level of a syntaxonomic alliance (Rodwell & *al*., 2002; Evans, 2006, 2010; Biondi & *al*., 2012), so all the Tuscan coenoses can be probably mostly attributed to the habitat Natura 2000 code 91M0, named "Pannonian-Balkanic Turkey oak-sessile oak forests" but found to be present also in the Italian peninsula, especially in the Thyrrenian side (see the Italian Interpretation Manual of the 91/43/EEC Directive Habitats - vnr.unipg.it/habitat; Biondi & Blasi, 2009).

Syntaxonomic scheme

Quercetea pubescentis Doing-Kraft ex Scamoni et Passarge 1959
Quercetalia pubescenti-petraeae Klika 1933
Crataego laevigatae-Quercion cerridis Arrigoni 1997
Crataego laevigatae-Quercenion cerridis Blasi, Di Pietro & Filesi in Di Pietro & *al.* 2010
Serratulo tinctoriae-Quercetum petraeae Ubaldi, Zanotti & Puppi 1995
Frangulo alni-Quercetum petraeae Arrigoni in Foggi & *al*. 2000
(=Ilici aquifolii-Quercetum petraeae Arrigoni 1997 nom. illeg. Incl.: *Hieracio racemosi-Quercetum petraeae fraxinetosum orni* Arrigoni 1997. Syn.: *Lonicero etruscae-Quercetum petraeae* Ubaldi 2003*)*
Corno maris-Quercetum petraeae ass. nova
Allio pendulini-Quercetum petraeae ass. nova
Junipero oxycedri-Quercetum petraeae ass. nova

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Additional material

Supplement 1. List of relevé sources, data and sites of the Tuscan *Quercus petraea* woods of Supplement 2.

Supplement 2. Phytosociological table of Tuscan woods in which *Quercus petraea* has relevant cover values.

Supplement 3. Classification dendrogram of Tuscan *Quercus petraea* woods.

Supplement 4. Synoptic table comparing different groups of Tuscan relevés showed in Supplement 2. Frequency (%) of species in each group. The PHI species of groups are in bold. Species with less than 7 occurrences in Supplement 2 are not showed.

Supplement 5. Synoptic table comparing the Tuscan relevé groups showed in Supplement 2 with the most similar associations from literature (in grey). Frequency classes of species in each table: 1 = 1-20%, 2 = 20-40%, 3 = 40-60%, 4 = 60-80%, 5 = 80-100%. The PHI species of Tuscan associations are in bold. Species with a frequency class = 1 in only one column are not showed. For association references see the main text.